REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-99-

0279

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. RE... DATES COVERED
15 Sep 98 to 14 Sep 99 Final

4. TITLE AND SUBTITLE
(STTR 98 Phase 1) Advances in high power optical fiber lasers

5. FUNDING NUMBERS
65502F
STTR/TS

6. AUTHOR(S)
Dr Wylangowski

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Hope Technologies, Inc
185 East Main Road
Little Compoton, RI 02837

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
801 North Randolph Street Rm 732
Arlington, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-98-C-0086

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVAL FOR PUBLIC RELEASED; DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

We have proposed and carried out a series of experiments that could be of significance to the development of high power cladding pumped optical fiber lasers. First, at low power, we have shown how a more complex cavity can result in increased power by combining fiber lasers using a truncated 2x2 coupler. We believe that this can lead to the concatenation of many couplers while still using the more convenient technique of end pumping. Experiments are in progress to investigate this concept further. Finally, we propose a technique, that has been demonstrated by others in Nd bulk glass, for increasing the ionic concentration of ytterbium and erbium in fiber lasers and still avoid problems associated with concentration quenching.

19991208 196

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Final Report:
Advances in High Power Fiber Lasers
STTR: F49620-98-0086
Report #3-0003AE

Hope Technologies, Inc.
185 East Main Rd., Little Compton, RI 02837

email: tfmorse@bu.edu

Introduction

The main focus of this effort by Hope Technologies, carried out at the Laboratory for Lightwave Technology at Brown University, was to develop improvements in high power cladding pumped optical fiber lasers. One of the main problems with these devices is the manner in which high power diode energy is coupled into the fiber. The traditional, and most commonly used technique is to end-pump the double clad fiber. This has the advantage of simplicity; however, the disadvantage is that since the optical fiber has only two ends, there can only be two high power diode sources available to provide energy to the fiber. This number can be doubled through the use of a dichroic beam splitter at the end of the optical fiber. This permits two pump sources at each end of the fiber as illustrated in Figure 1. At the last CLEO meeting, SDL reported achieving over 110 W output power (CW) from four 50 W diode pump sources. It is clear that there is a limit to the output power that can be obtained in this manner, although 110 W CW is clearly an impressive amount of power to be transported through a cladding pumped fiber with a single mode Yb core.

An alternate approach has been taken by Gapontsev, of IRE-Polus. Unfortunately, outside of the results presented by this group, there is little detail as to how their fiber is pumped. At the recent OSA Santa Clara meeting, Gapontsev presented an invited paper in which he highlighted some of the recent work of his group. He stated that, again with a Yb fiber, he was able to obtain single mode operation at the level of 500 W CW. This is significantly higher than achieved by any other research group. In addition, for a multi-mode fiber (it was not clear if this fiber was a multi-core fiber) he reported 1,200 W CW for an extended period of time. He believe that with the solution of some tractable heat transfer problems, this value could be increased to 1,500 W CW. At this level, there are innumerable commercial applications to which such a device might be applied. A Nd-Yag system of comparable power is an expensive, heavy, and complex system.

Alternate Techniques for Combining Diode Pump Sources for Fiber Lasers

First, consider a 2 x 2 fused taper coupler as illustrated in Figure 2. If we then cleave this coupler at the midpoint, then the intensity emanating from this cleaved section will have a close approximation to a Gaussian distribution of intensity. We now "write" Bragg gratings in the other end of the fibers. This can be used as a means to concatenate or render coherent individual fiber lasers.

We know that the output from two different fiber lasers can have the same intensity, the same wavelength, yet, they will not be coherent with respect to one another. In this case, if we pump both ends of the fiber, the two arms of this "wishbone" cavity will be coherent with one another. The reason is that there are not two individual cavities, but one single cavity of a rather strange shape. If this 2 x 2 coupler is cleaved either before or after the midpoint of the waist section, then, two overlapping spots will define the intensity. This is no surprise. Cleaving at the waist section, however, results, as has been noted, in a Gaussian type output intensity. In Figure 4, we have used the "wishbone" cavity with Bragg gratings on each pump end, and with the cleave (air-glass interface) serving as the output coupler. If one branch is pumped, this corresponds to curve 2 in this figure. If the other branch is pumped, we obtain the result of curve 3. If both branches of the "wishbone" are pumped, we obtain curve 1. It should be noted that curve 1 is essentially the sum of curves 2 and 3. That is, the intensities add. This would also be the case if we had two separate fiber lasers. The difference is that the output of curve 1 is additive, and that the output is coherent. There is only a single cavity. The discrepancy between magnitude and distribution of the intensities laser output of the two individual fibers can be attributed to different power of the two pump diodes and the efficiency with which they are coupled into the fiber ends through the Bragg gratings.

That the output when both ends of the "wishbone" are pumped is coherent can be inferred through the following experiment. If we strain tune one Bragg gratings on the ends at which the fiber is pumped, then if one of these gratings is strained beyond a certain difference in wavelength compared with the unstrained Bragg grating, we obtain the spectral distribution at the cleaved output coupler is that shown in Figure 5. As we release the strain on the fiber the wavelengths approach one another until the cavity "locks" on one wavelength. Thus, the output consists of a single wavelength (clearly there will be longitudinal modes associated with the length of the cavity. This concept can be exploited to increase fiber laser output power in the following manner.

Fused Taper Couplers and Cladding Pumped Fiber Lasers

We have thus far established, in principle, a technique by which it is possible to combine fiber lasers in a coherent manner. This was done with low powers, and the question remains as to how to implement this concept at high powers. Although the limitations of doped silica have yet to be established with certainty, according to the recent work of Gapontzev (IRE-Polus), 500 W CW were obtained in a Yb cladding pumped fiber laser. This means that the single mode core was able to withstand this power density. This leads us to consider the following, which we have not yet carried out experimentally. If the core can withstand this power density, then we can imagine a 2 x 2 coupler with a waist section of the order of 10 microns carrying 500 W of CW radiation. The maximum power density would be in the necked down section of the coupler, and everywhere else, the power density would be significantly reduced. Thus, if a 2 x 2 coupler were made of a 300 micron fiber, and this is a standard item available from Gould, then we could pump each end of this coupler and obtain a cavity configuration as indicated in Figure 6. If this multimode fiber were fabricated from a cladding pumped design, i.e. a multimode first cladding that surrounds a single mode rare earth doped core, then we have doubled the

number of points at which this can be pumped. Instead of pumping two ends, we now have four, and, should the polarizing beam splitter technique that SDL has reported be used, a conceivable eight high power diode sources could be employed. Thus, we would have an x shaped cavity that would be similar to a Fox-Li resonator. The output would be single mode (transverse). This concept can be extended, as indicated in Figure 7. This configuration provides for six individual "ends" at which high power diode radiation may be focused into the multimode guiding structure. End pumping is the most direct and simplest technique for introducing power into the cladding pumped structure, and this concept provides a means for increasing the number of "ends" in the fiber laser. We have not yet performed these experiments, mainly due to the move of the Laboratory for Lightwave Technology from Brown University to Boston University. However, it is hoped that preliminary work on this can be carried out in the near future.

If this concept proves viable, we believe that a new type of cladding pumped fiber laser will result. This will have significant commercial applications, and we would hope, having developed such a device, that an application for further STTR support would be welcomed.

Preliminary Work on Zeolites to Reduce Concentration Quenching

In order to increase the power density from any lasing source, in principle, it should be necessary only to increase the number of active ions. In a glass, this can be carried out until a limit on the solubility of the ion is reached, at which point, crystallization or phase separation occurs, thus increasing the scattering of the material significantly. Thus, we might imagine that we should keep increasing active ion density until this situation is reached. Unfortunately, this is not the case. A phenomenon known as concentration quenching sets in far before this limit of undesirable scattering is reached. If the active ions become too close together, then the radiation field of an emitting atom can interact with a neighboring atom, and they will merely exchange energy with one another, thus reducing the contribution to the lasing field. If these atoms can be moved further apart, then this undesirable mutual interaction is reduced. The distribution of active rare earth ions in a silica matrix is, however, not uniform. This is a consequence of the differences in the coordination numbers of the rare earth ions and the silica host. As a consequence, the rare earth ions tend to agglommerate and form clusters of higher concentrations than if they were uniformly distributed. Thus, concentration quenching sets in at an earlier stage than if molecular homogeneity were possible.

This undesired concentration quenching can be reduced by reducing the average rare earth concentration. We would like to avoid this, since the power density/volume is reduced. This has its consequences for high power cladding pumped lasers, as well as for fiber lasers that may play a role in switching of high speed transmission. The higher the concentration (without incurring concentration quenching), the shorter the laser can be, which means that pulses will propagate faster in a shorter fiber laser. In the following we propose a means by which it may be possible to avoid concentration quenching in fiber lasers. Some preliminary experiments have been carried out, and we hope to pursue this topic further, since it is of possible significance.

Zeolites are complex crystalline structures that consist of Si and Al atoms. Depending upon the specific zeolite in question, they typically have structure that resembles an "igloo" with eight entrances. Within these entrances, and in the central section of the "igloo", ions are trapped. Typically, Na ions are encased in these structures. These materials are used in great quantities as matrices for ion exchange. It has been shown that it is possible to ion exchange the Na ion for an ammonium ion (NH4), and that the ammonium ions can be exchanged for rare earth ions. (Charge neutrality naturally being maintained). These rare earth ions that sit in these cages are now restrained from coming too close together, and the inter-atomic separation of the rare earth ions is nearly the ideal minimum distance below which concentration quenching occurs. We have not yet demonstrated that it is possible to incorporate such a concept in a rare earth doped optical fiber; however, one of the crucial experiments toward the success of this has already been carried out. The zeolites are crystalline, and should they be present in the core of an optical fiber, unacceptable scattering losses would occur, even for the relatively short distances associated with cladding pumped fiber lasers. Just as crystalline silica can become amorphous while retaining a semblance of its crystalline structure, we have been able to process zeolites in the core of an optical fiber at the 2,150 centigrade temperature necessary for MCVD processing of a silica substrate tube. The decomposition temperature of the zeolite is several hundred degrees lower, but it seems that the silica boundary on the zeolite prevents its decomposition, and this relatively complex structure seems to achieve an amorphous form. We believe that the average separation distance for the caged rare earth ions will be maintained, and that it will be possible to increase the ionic density of, for example, erbium or ytterbium ions in a silica core. This would be an important contribution toward the goal of more powerful, lighter weight cladding pumped optical fiber lasers.

Conclusions

We have proposed and carried out a series of experiments that could be of significance to the development of high power cladding pumped optical fiber lasers. First, at low power, we have shown how a more complex cavity can result in increased power by combining fiber lasers using a truncated 2 x 2 coupler. We believe that this can lead to the concatenation of many couplers while still using the more convenient technique of end pumping. Experiments are in progress to investigate this concept further. Finally, we propose a technique, that has been demonstrated by others in Nd bulk glass, for increasing the ionic concentration of ytterbium and erbium in fiber lasers and still avoid problems associated with concentration quenching.

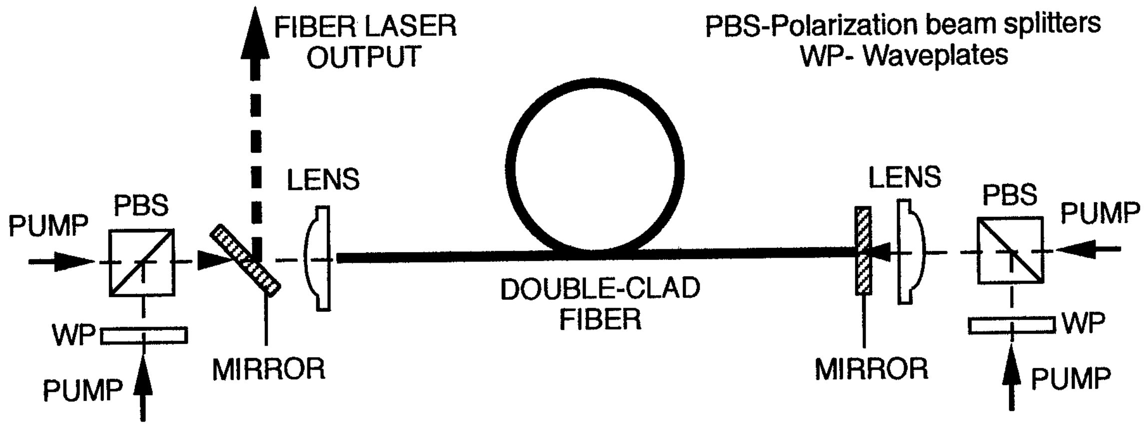

Figure 1. Use of dichroic beam splitter for doubling diode end pumps.

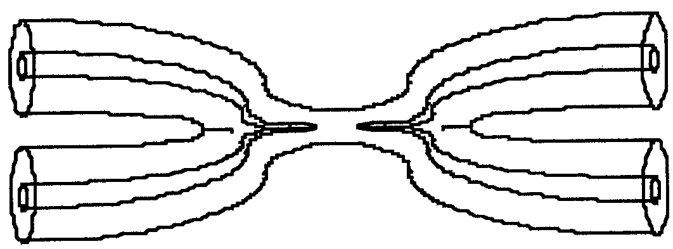

Figure 2. A 2x2 fused taper coupler.

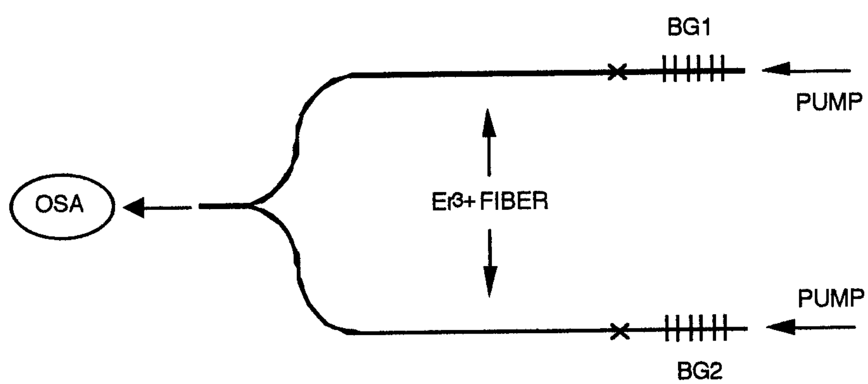

Figure 3. Cleaved 2x2 fused taper coupler.

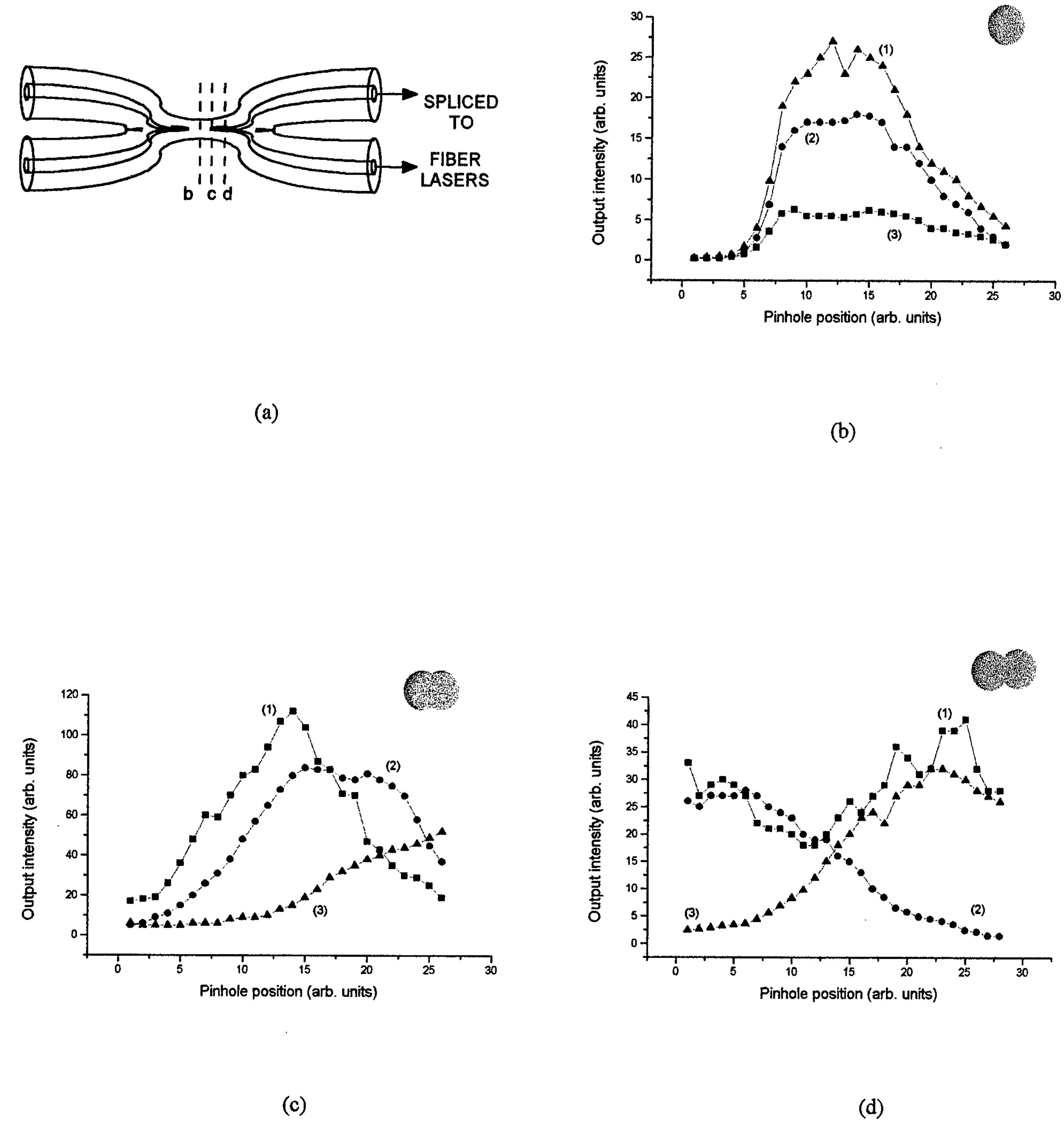

Figure 4. Output intensity for different pumping conditions.

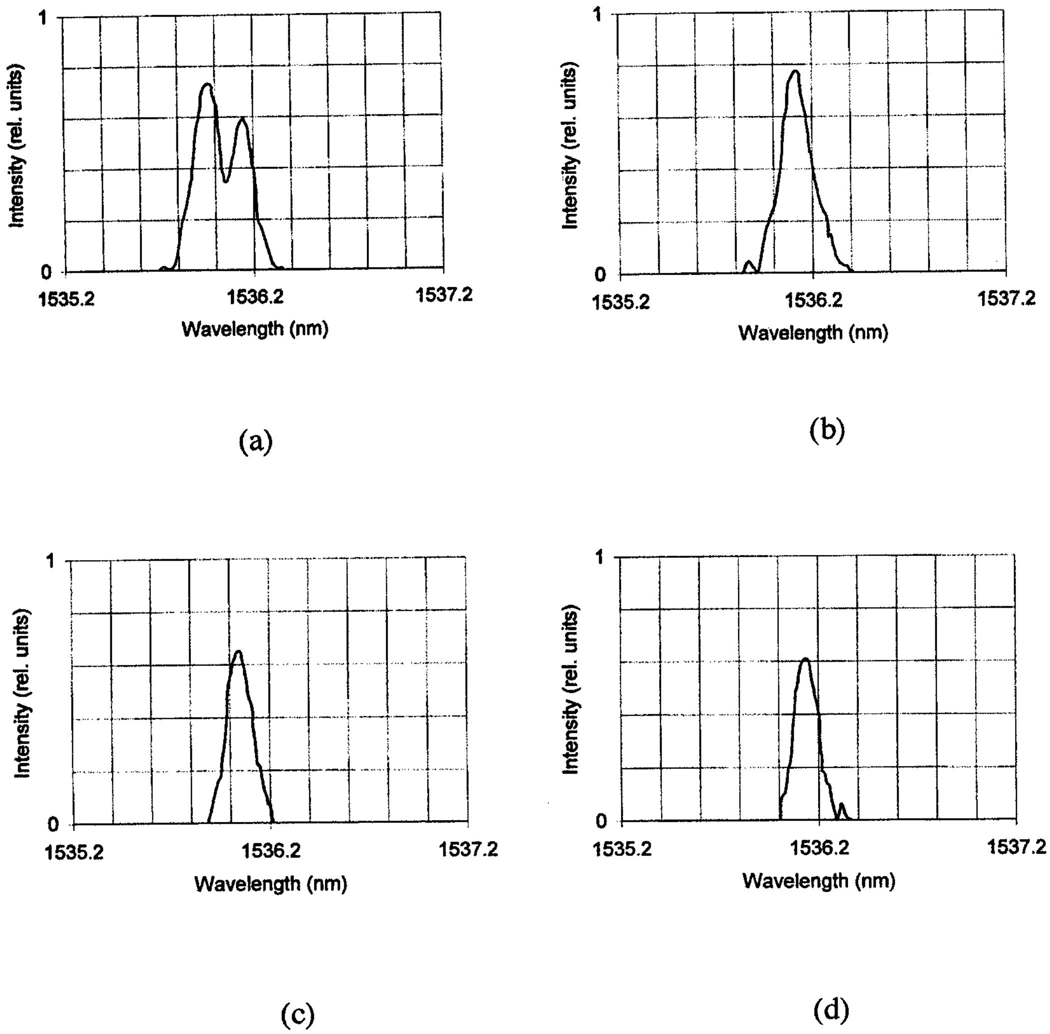

Figure 5. Strain detuning of Bragg grating in "wishbone" fiber.

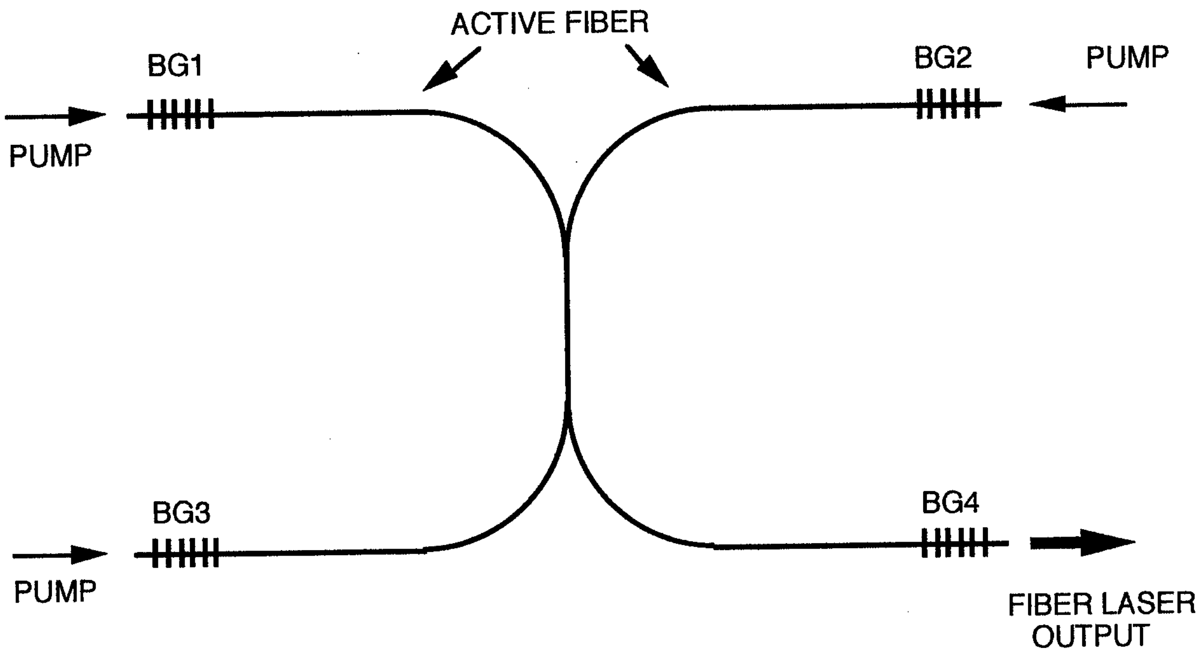

Figure 6. A 2x2 coupler as a fiber laser cavity.

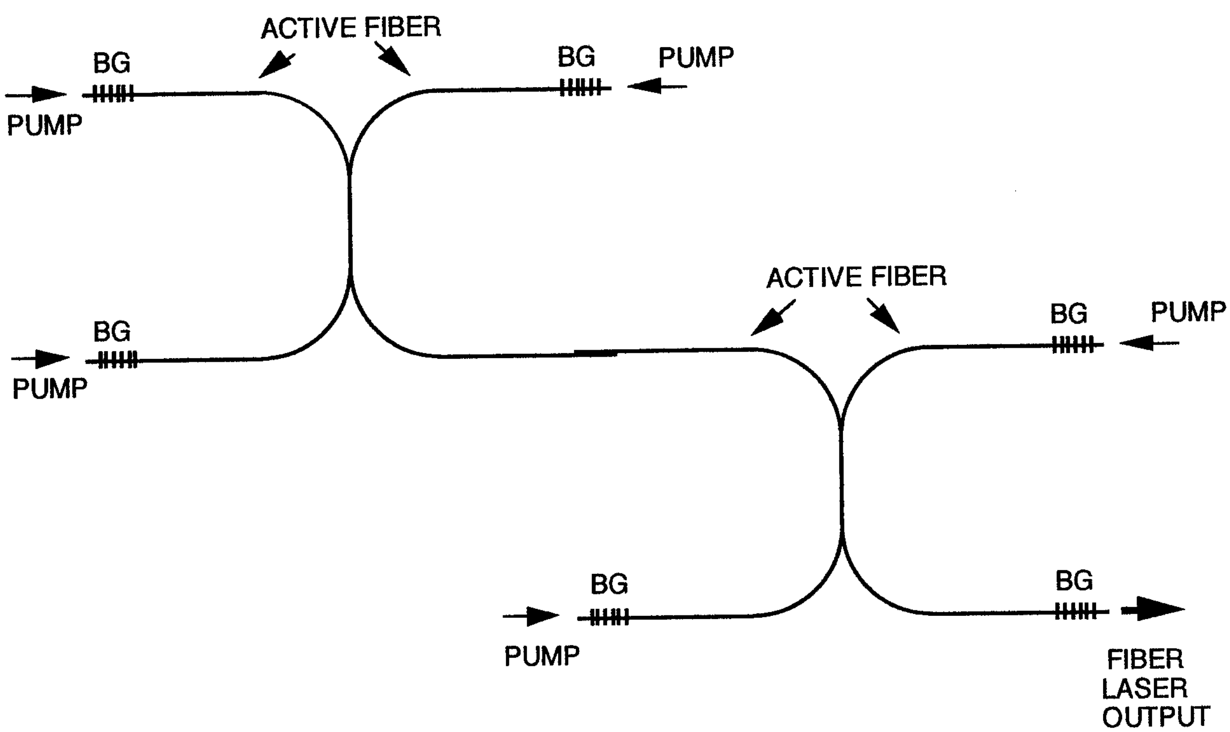

Figure 7. Two 2x2 couplers as a fiber laser cavity.